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Approaches to analyse and model changes in impacts: reply to discussions of “How to improve attribution of changes in drought and flood impacts”

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REPLY

Approaches to analyse and model changes in impacts: reply to discussions of "How to improve attribution of changes in drought and flood impacts"*

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ABSTRACT
We thank the authors, Brunella Bonaccorso and Karsten Arnbjerg-Nielsen for their constructive contributions to the discussion about the attribution of changes in drought and flood impacts. We appreciate that they support our opinion, but in particular their additional new ideas on how to better understand changes in impacts. It is great that they challenge us to think a step further on how to foster the collection of long time series of data and how to use these to model and project changes. Here, we elaborate on the possibility to collect time series of data on hazard, exposure, vulnerability and impacts and how these could be used to improve e.g. socio-hydrological models for the development of future risk scenarios.

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The Panta Rhei opinion paper series intends to foster scientific discussion about approaches to increase our knowledge of interactions and feedbacks between hydrology and society (https://think.taylorandfrancis.com/panta-rhei-collection; Kreibich *et al.* 2017). Thus, we are grateful to the authors, Bonaccorso (2020) and Arnbjerg-Nielsen (2020), for supporting our view and for their constructive comments on our opinion paper "How to improve attribution of changes in drought and flood impacts" (Kreibich *et al.* 2019). Both authors back up our appreciation that droughts and floods have much in common and that flood risk management measures may influence drought risk, and *vice versa*, partly because of inadequate land management practices. Furthermore, both authors agree on the need for a closer cooperation between drought and flood experts to carry out joint analysis of the effects of flood and drought management on impact changes, which is important for scientific advancement in this area. Bonaccorso (2020) stresses that, in addition to interdisciplinary teamwork of experts with a natural sciences or engineering background, a broader debate and closer cooperation with water resources economists and socio-political scientists is necessary for sustainable, pro-active risk management, which focuses on adaptive solutions to cope with droughts and floods in the future.

There are convincing examples of such successful cooperation in practice as well as in science. We cannot provide an overview here, particularly not about the many good activities happening in practice, but we give some examples. For instance, hydrologists, economists and geographers have together developed the cost assessment cycle, which involves the continuous monitoring and reduction of the total costs associated with natural hazard impacts and risk management, thus enabling the early detection of inefficient risk mitigation strategies (Kreibich *et al.* 2014). Psychologists, economists, political scientists, physical geographers and urban planners are working together to better understand relocation decisions to reduce flood risks (Bukvic *et al.* 2015, Botzen *et al.* 2016). In a collaboration between human and physical geographers, international development specialists and hydrological modellers, Rangecroft *et al.* (2018) explored interdisciplinary ways to increase preparedness for drought. Breyer *et al.* (2018) present the work of an engineer and a geographer who modelled the feedbacks between drought and urban water-use restrictions. They conclude that "*adapting to anthropogenic drought requires sustained engagement between hydrology and social sciences to integrate socioeconomic status and political feedbacks into the water cycle.*" In the EU-funded project DROUGHT-R&SPI (http://www.eu-drought.org/), economists and political scientists worked together with weather-related hazard experts on economic losses in Southern European agriculture (Musolino *et al.* 2018). The study reveals

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that drought does not have only "losers", but also "winners". In their case, farmers were the winners, while the consumers were the losers. These findings also refer to the suggestion of Arnbjerg-Nielsen (2020) to investigate how stakeholders are differently affected, e.g. citizens *versus* agriculture.

However, we agree that interdisciplinary cooperation should be further strengthened in drought and flood research. This is especially crucial if we want to model drought and flood risks using improved scenarios for exposure and vulnerability, as suggested by Arnbjerg-Nielsen (2020). Such scenarios cannot be developed without a strong collaboration with social scientists. In recent years, a rethinking towards the need for more inter- and transdisciplinary research projects began. Nevertheless, collaboration between physical and social scientists requires extra time that needs to be invested in order to gain sufficient mutual understanding of concepts, approaches and models, which is often difficult to justify in research proposals. The well-established inclusion of some social scientists in the Panta Rhei initiative and working groups is a step in the right direction (https://iahs.info/Commissions–W-Groups/Working-Groups/Panta-Rhei/Working-Groups.do). However, it is unclear if and how this cooperation will continue after the end of this scientific decade in 2022 (Montanari *et al.* 2013, McMillan *et al.* 2016). The European Commission should include in their RTD programme (e.g. upcoming Horizon Europe) calls for projects addressing interdisciplinary cooperation on changes in risk of weather-related natural hazards, including floods and droughts due to global change.

Arnbjerg-Nielsen (2020) acknowledges the challenge of compiling matching data of impacts and their potential drivers for catchments or regions, which is especially true for droughts where impacts are not always directly attributable to the hazard (Kreibich *et al.* 2019). Recently a global inventory was made for drought risk assessment, consisiting of over 200 datasets, tools, indicators, text-based information, etc. (Hendriks *et al.* 2018, World Bank 2019), which shows that most available data are on (historical) drought hazards, whereas impact data are very limited or even lacking. Bonaccorso (2020) provides hope, however, that impact and other data will become increasingly available through private initiatives of big on-line service providers, such as Google, or insurance companies. Indeed, in recent years, new data sources such as those derived from satellite images, from crowd sourcing on social media, from measurements of innovative sensors, or gained in a participative way, e.g. when citizens provide information, are gaining more and more importance in science and application domains.

Several studies have shown the significant potential that data science can encompass for natural hazards research. For instance, crop data derived from a multi-year satellite image analysis and ancillary soil data were analysed with data mining Net Bayesian Classifiers to support the estimation of flood losses to agricultural crops. The approach was validated in flood retention areas at the Havel River, which were used for temporary storage of flood water during the extreme flood event in August 2002 in Germany (Tapia-Silva *et al.* 2011). Sieg *et al.* (2019) developed an approach for seamless damage estimation including uncertainty quantification, which is based on open access building data from openstreetmap.org that is collected in a participatory way, in combination with random forest based loss modelling. In Florida, USA, citizens are helping to collect information on flooded locations and other data during flooding in high-tide events (SLSC 2019). News media data are also increasingly used in flood and drought risk studies. For example, Quesnel and Ajami (2017) used news media coverage and Google search frequency to study drought awareness in California, USA, between 2005 and 2015. They found that residential water use was strongly related to the news media coverage. A promising governmental tool of the European commission is the Europe Media Monitor (EMM), which was initially developed to globally monitor outbreaks of diseases. "*Monitoring thousands of news sources in over 70 languages, the system uses advanced information extraction techniques to automatically determine what is being reported in the news*" and could be adapted to scan for impacts of natural hazards (Steinberger *et al.* 2013).

Bonaccorso (2020) stresses the need for international standards for impact data collection and she suggests that the scientific community should be in charge of developing general guidelines. There are several scientific studies aiming to define what data should be collected for which purpose and how (e.g. Elmer *et al.* 2010, Van Lanen *et al.* 2016, Molinari *et al.* 2018). Impact data collections are undertaken by different stakeholders after drought and flood events: scientists collect impact data to gain knowledge about damage processes, governmental agencies and insurance companies collect data in the framework of loss compensation. Scientific assessments often contain a lot of detail, but suffer from a relatively small sample size (Blong 2004, Mazzorana *et al.* 2014). Data collected by government agencies and insurance companies are often classified and not accessible for research. Thus, a closer cooperation between these different stakeholders would be advantageous. Among other important developments are the EU initiatives for recording and sharing disaster damage and loss data (https://drmkc.jrc.ec.europa.eu/partnership/Science-Policy-Interface/Disaster-Loss-and-Damage-Working-Group; JRC 2013), and the OECD initiative to develop a framework for accounting risk management expenditure and losses due to disasters (OECD 2014). Nongovernmental organizations (NGOs) also play an important role as intermediaries, including aid and other relief organizations in developing countries, where public authority capacity is lower compared to developed countries. For instance, the Red Cross is active in collecting disaster event data and also in developing algorithms to predict where and when impacts can be expected in the future (Van den Homberg *et al.* 2018).

With reference to the proposed paired-event approach, Bonaccorso (2020) suggests that it would be essential for better detecting changes in vulnerability to go back in time to find a baseline scenario, where almost no risk-reduction intervention has been put in place yet. We are not so sure about the possibility of such a baseline scenario, since humans have been managing water already for centuries to millennia in many areas around the world and often no data predating human interventions exist (e.g. Kuil *et al.* 2016, Ochoa-Tocachi *et al.* 2019). However, we agree that the paired-event data would gain significantly in value if the data at the two points in time (i.e. for the two events) could be extended with longer time series of hazard, exposure, vulnerability and impact data, indicators or proxies. That means, it would be interesting to check the availability of time series of the variables that have been collected for paired-event case studies (Table 2 in Kreibich *et al.* 2019). As suggested by Arnbjerg-Nielsen (2020), processes and variables that are difficult to monitor might be represented via modelling approaches, i.e. constructed time series data, such as from regional climate models. Such an extended dataset would enable time series analyses of impacts and their drivers (e.g. Bubeck *et al.* 2012, Safavi *et al.* 2014, Blauhut *et al.* 2015; Sutanto *et al.* 2019) to gain more knowledge about the temporal dynamics of drought and flood risk processes, causes and consequences. Also, Erfurt *et al.* (2019) proved the added value of long-term data going back to the early 19th century, showing that the severity of recent drought events is nothing new, while underlying vulnerabilities might have changed as indicated by drought impact reports.

Arnbjerg-Nielsen (2020) stresses the need to develop modelling approaches to enable the projection of drought and flood risk. He suggests that many regions of the world are very likely to experience more water extremes in the future, i.e. an increase in the occurrence and magnitude of both droughts and floods in the same catchments. Using historical data might underestimate the linkages that are important for risk management even in the near future (Arnbjerg-Nielsen 2020). Indeed, more quantitative knowledge about possible future developments together with an adaptable risk management strategy is urgently needed (Kreibich *et al.* 2014). One of the big challenges is to develop the "*reasonable scenarios for exposure and vulnerability*" that Arnbjerg-Nielsen (2020) mentions. To develop plausible future scenarios, more (semi-)quantitative analysis of dynamic vulnerability of historic events is needed, so that past trends may be extrapolated into the future, with the possibility of assuming different trends in vulnerability reduction (see e.g. Jongman *et al.* 2015). Additionally, the application of stress test scenarios is a promising novel approach to gain insights for possible future conditions (e.g. Guillod *et al.* 2018, Zischg *et al.* 2018, Stoelzle *et al.* 2020). Such stress test scenarios will "*help to explore the resilience of socio-ecological systems to droughts*" (Hall and Leng 2019). Additionally, the above-mentioned long-term datasets might be used to improve socio-hydrological models (e.g. Barendrecht *et al.* 2019), or other models that could be used to project the dynamics of drought and flood risk. According to Barendrecht *et al.* (2017) and Aerts *et al.* (2018) other models that are able to describe the interaction of hydrological and anthropogenic processes are system-of-systems models (e.g. O'Connell and O'Donnell 2014, Falter *et al.* 2016, Metin *et al.* 2018), or agent-based models (e.g. Haer *et al.* 2016, 2019, Jenkins *et al.* 2017). For example, Barreteau *et al.* (2014) developed an agent-based model to evaluate the suitability of different drought indicators for different stakeholders. Examples are, however, very limited and more research in this direction would certainly be very valuable. This can help answer the question "How can we extract information from available data on human and water systems in order to inform the building process of socio-hydrological models and conceptualisations?", which is listed by Blöschl *et al.* (2019) as one of the 23 unsolved problems in hydrology.

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